EFFECTS OF DIFFERENT LARGE-SCALE PRESCRIBED BURNING REGIMES ON ADVANCE REPRODUCTION IN THE MISSOURI OZARKS

Daniel C. Dey and George Hartman[1]

Abstract—In 1997, The Nature Conservancy initiated a large-scale prescribed fire management study on approximately 2,500 acres of their Chilton Creek property located in Shannon and Carter counties, Missouri. Since the spring of 1998, five management units, of roughly 500 acres each, have been burned in the dormant season to simulate a range of fire regimes that vary from annual fires to fire free intervals that average from 1 to 4 years. The intent is to simulate high frequency, low intensity fires that occurred historically in the watershed and study fire effects on the biota. The overstory was inventoried on half-acre permanent plots located in the different burn treatments. Survival and height growth of the advance reproduction was recorded on smaller plots nested within the half-acre plots. In this paper, we present the effects of the different burning regimes on the advance reproduction.

INTRODUCTION

Over the past 400 years or more, fires burned throughout the Ozarks, shaping the nature of the vegetation (Ladd 1991, Guyette and Cutter 1991, Cutter and Guyette 1994, Guyette and others 2002). The frequency of fire varied across the Ozarks with changes in topography and was modified throughout time by humans. The net result was a mosaic of pine and oak savannas and woodlands and mesic hardwood forests (Batek and others 1999). Today, however, fire occurrence in the Ozarks has been drastically reduced. In Missouri, fires usually burn less than 50,000 acres per year throughout a 16 million acre area that encompasses the Ozark Highlands (Westin 1992). Individual fires average less than 20 acres, and humans cause nearly all (> 99 percent) of these fires.

Since the advent of fire suppression in the 20th century, savanna and woodland communities have developed into mature, closed-canopied forests as tree density and stocking and vertical structure of woody species have increased. Managers of federal and state natural resource agencies are reintroducing fire using prescribed burning to restore oak/pine savannas and woodlands, to restore glade and fen communities, to promote native biodiversity, and to restore historic disturbance regimes. Large area burns (500 acres to 7,000 acres) are being done throughout the Ozarks.

The Nature Conservancy (TNC) is restoring fire through prescribed burning on approximately 2,500 acres of their Chilton Creek Preserve in the Missouri Ozark Highlands. Their fire plans are guided by information provided by Guyette and others (2002) who have documented mean fire intervals of 3.6 and 4.1 years just west of Chilton Creek during the historic period 1700 to 1820, which predates most European settlement in the area. TNC's management objective is to use fire to restore the quality and ecological integrity of terrestrial natural communities and improve habitat for species of conservation concern in the Ozarks where fire has long had a strong influence on ecosystem structure and function. They are intensively monitoring the response of vegetation and other selected biota to a set of fire treatments that differ primarily in the frequency of burning. In this paper, we present the response of tree advance reproduction after four years of implementing the fire treatments.

METHODS

The Chilton Creek Preserve is a 5,657 acre site located along the Current River in Shannon and Carter Counties, Missouri (T 28 N, R 1 W) (fig. 1). The site lies within the Current River Hills subsection of the Ozark Highlands (Keys and others 1995), an area characterized by rugged, steeply dissected valley and hollows and narrow ridges (approximately 500 foot relief). The area is covered in relatively continuous oak-hickory and oak-pine woodlands and mature forests growing on excessively drained cherty clay residuum. Based on an inventory of overstory trees [with diameter at breast height (d.b.h.) ≥ 4.5 inches], we found that basal area averaged 79 ft^2 per acre (range 38 to 160), and stocking was 69 percent (range 36 to 120) [according to Gingrich (1967)] on the subset (n = 26) of circular half-acre plots used in our study.

The Chilton Creek watershed was divided into five management units (fig. 1) of approximately 500 acres each (table 1). All units were burned in the spring of 1998 to initiate the process of restoring fire. Thereafter, units were burned during the dormant season (usually in March or April) on a randomly selected 1 to 4 year return interval basis, with the exception of the Kelly North management unit, which was burned annually (table 1).

We sampled individual stems of advance reproduction on 26 of the 250 (0.5-acre) permanent vegetation plots (fig. 1). Initial stem measurements were done in the fall of 1997, before the first burn. We recorded species, stem basal diameter one-inch above the ground, d.b.h., and height on 2,741 stems that were distributed among the five management units (table 1). Overall, the basal diameter of all stems

[1] Research Forester, USDA Forest Service, North Central Research Station, Columbia, MO 65211; and Fire Ecologist, Missouri Department of Conservation, Columbia, MO 65201, respectively.

Citation for proceedings: Spetich, Martin A., ed. 2004. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS–73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 311 p.

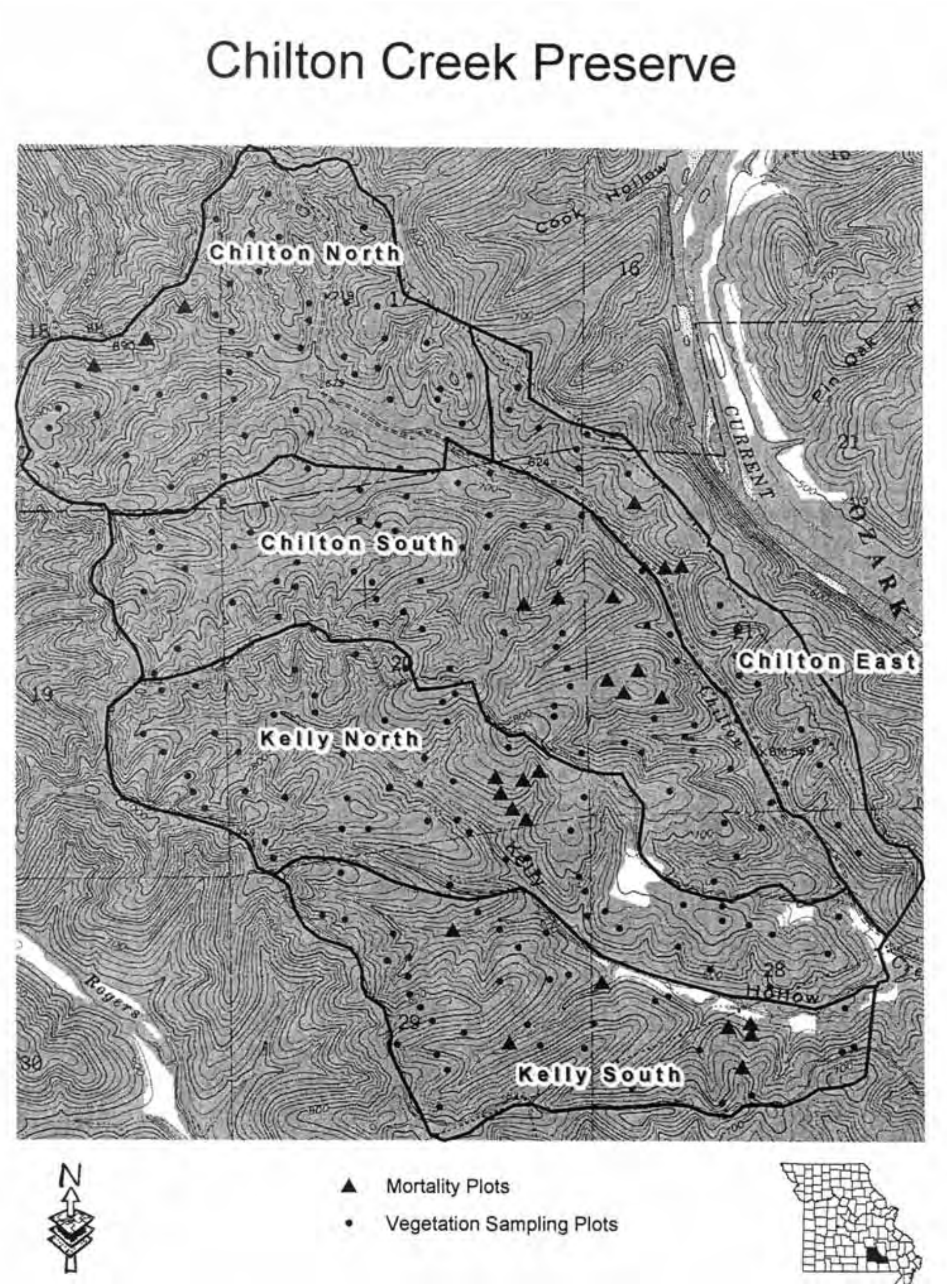

Figure 1—Location of the Chilton Creek Preserve and study area with locations of vegetation sampling plots (circles) and the subset of plots (triangles) we used to evaluate the effects of fire on advance reproduction.

Table 1—Schedule of prescribed burns conducted at Chilton Creek during the dormant season in each of the management units; size of each unit with the distribution of study trees is also presented

	Dormant season fire					Advance
Burn unit	1998	1999	2000	2001	Acres	reproduction (N)
Kelly South	X		X	X	403	363
Kelly North	X	X	X	X	603	542
Chilton South	X	X	X		725	1,123
Chilton North	X				464	358
Chilton East	X				254	355

ranged between 0.1 and 6.0 inches, and heights varied from 0.1 to 50 feet (table 2). In the fall of 1998 and 2001, we inventoried all stems and counted the number of sprouts and measured the height of the tallest sprout for surviving trees that had been topkilled by previous fires.

Fuel loading was estimated before each burn using two permanent 50-foot transects on each plot following the methods of Brown (1974) and Brown and others (1982). Total fuel loads averaged 4.3 to 5.9 tons per acre for any given burn year, and herbaceous/litter fuels accounted for much of the total tonnage (table 3). Weather conditions before each burn were recorded onsite using a belt weather kit or Kestrel 3000 weather meters. Weather during the burn was recorded at the National Park Service station located 4 miles from the study area. Temperatures during most burns were between 60 to 75 °F, winds were generally less than 4 miles per hour, and relative humidity ranged from 33 to 44 percent (table 3).

During each burn, we estimated flame length, rate-of-spread and flaming front temperature (table 3). Flame length was measured with passive flame height sensor arrays, which consisted of 20 lengths of cotton string soaked in flame retardant that were suspended from wires positioned 10 feet above the fuel bed. Visual measurements of flame angles were used to convert flame height to flame length according to Ryan (1981) and Finney and Martin (1992). Visual estimates of flame lengths were also made during the burns by observers. Flame lengths were highly variable but often were in the range of 1 to 3 feet. Rate-of-spread was determined by direct observation using a stopwatch to time the movement of the flaming front over a known distance or by using arrays of modified clock assemblies that were buried in the soil along a transect (Grabner 1996). Rates-of-spread were also variable, but the fire front usually moved at a rate of 3 to 16 chains per hour. Fire temperature along the flame front was measured using temperature sensitive paints applied to aluminum tags that were suspended from 9 gauge

Table 2—Pre-burn seedling and sapling basal diameter, diameter breast height, and total height[a]

Species	N	BD	D.b.h.	HT
		- - - - - *inches*	- - - - -	*feet*
White oak	346/185	1.4 ± 1.5	1.9 ± 1.2	10.8 ± 11.7
Scarlet oak	156/56	1.0 ± 1.4	1.9 ± 1.3	7.3 ± 11.4
Blackjack oak	56/25	1.7 ± 1.8	2.9 ± 1.1	9.6 ± 10.5
Chinkapin oak	106/31	0.6 ± 0.9	1.2 ± 1.0	4.6 ± 6.3
Post oak	180/79	1.2 ± 1.4	2.0 ± 1.1	7.8 ± 9.4
Black oak	224/92	0.9 ± 1.3	1.6 ± 1.3	7.5 ± 10.6
Pignut hickory	299/179	1.4 ± 1.4	1.8 ± 1.0	10.7 ± 10.8
Black hickory	128/53	1.1 ± 1.2	1.6 ± 1.1	6.9 ± 7.5
Mockernut hickory	296/153	1.0 ± 1.1	1.3 ± 0.9	7.5 ± 7.4
Flowering dogwood	316/192	1.4 ± 1.3	1.7 ± 1.0	10.1 ± 12.2
Blackgum	240/156	1.3 ± 1.2	1.5 ± 0.9	9.7 ± 7.8
Persimmon	32/10	0.5 ± 0.5	1.0 ± 0.5	4.3 ± 4.9
White ash	65/29	0.9 ± 0.9	1.2 ± 1.0	6.7 ± 6.0
Sassafras	286/115	0.8 ± 1.0	1.4 ± 0.9	7.3 ± 8.0
Shortleaf pine	74/53	1.9 ± 1.5	2.0 ± 1.2	11.5 ± 7.9

BD = basal diameter; d.b.h. = diameter at breast height; HT = total height; N = the first sample size.

[a] The first sample size is given for BD and HT, and the second is for d.b.h. (means and one standard deviation are presented).

Table 3—Fuel conditions, fire weather, and behavior for each of the prescribed burns

		Fuel characteristics							Weather					Fire behavior		
		Moisture			Load									Temp.		
Burn year	Slope	1-hr.	10-hr.	100-hr.	1-hr.	10-hr.	Herb.	Total	Wind	Temp.	RH	FL	ROS	Surface	1-ft.	2-ft.
	- - - - - - - *percent*	- - - - - - -			- - - - - *tons per acre*	- - - - -			*mph*	*°F*	*%*	*ft.*	*ch/hr*	- - - - - *°F*	- - - - -	
1998	4 – 36	8	8	13	0.24	0.94	3.5	5.9	2 – 4	65 – 75	39	3.2	15.8	589	309	246
1999	11 – 25	8	8	16	0.27	1.4	1.8	4.3	0 – 2	59 – 69	44	1.0	5.9	361	179	154
2000	4 – 33	7	7	14	0.3	1.6	2.2	5.2	0 – 2	68 – 76	36	1.5	6.5	470	232	184
2001	4 – 33	7	7	12	0.24	1.3	1.9	4.6	0 – 2	50 – 64	33	1.1	2.7	250	153	150

steel rods (Cole and others 1992). Tags were hung at the fuel surface, and at 1- and 2-foot heights above the fuel surface on each rod. Temperatures were highest at the fuel surface (ground level) and reached 250 and 600 °F.

For each species, we used logistic regression (Allison 1999) to model the probability of survival in 1998 (after one burn) based on initial basal diameter, initial height, and the interaction between basal diameter and height. Similarly, we modeled the probability that a stem of advance reproduction would be alive in 2001 (4 years after burn treatments were begun) based on initial stem size and number of times the reproduction was burned. We used an information-theoretic approach to modeling the probability of survival for advance reproduction that had experienced prescribed burning (Burnham and Anderson 2002). The set of apriori models for each species was ranked using Akaike's Information Criterion, AIC, which were adjusted for small sample sizes (AIC_c) when necessary. AIC values were used to compute the $\triangle$AIC and Akaike weight (w_i) for each model. These statistics (i.e., $\triangle$AIC and w_i) were used to identify models that performed well and for estimating the support a model had for being the best. Models with a lower $\triangle$AIC and a greater w_i have more support for being the better models of those being compared. In all comparisons for a species, we included the null (intercept only) model.

RESULTS AND DISCUSSION

1998 Fire Damage – After One Burn

Mortality of advance reproduction after one spring burn was generally below 10 percent for most species (table 4). Mortality was low (i.e., < 5 percent) in hickory (*Carya*), blackgum (*Nyssa sylvatica* Marsh.), sassafras (*Sassafras albidum* (Nutt.) Nees), chinkapin oak (*Quercus muehlenbergii* Engelm.), and blackjack oak (*Quercus marilandica* Muenchh.). Sassafras had the lowest mortality (0.3 percent) and shortleaf pine (*Pinus echinata* Mill.) had the highest (38 percent). White oak (*Quercus alba* L.), post oak (*Quercus stellata* Wangenh.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), and flowering dogwood (*Cornus florida* L.) experienced relatively moderate levels of mortality (i.e., 5 to 10 percent). For all species, stems of advance reproduction averaged about 1 inch in basal diameter (table 2), and diameters ranged from 0.1 to 6.0 inches.

We found that initial basal diameter and height of advance reproduction were significantly (α = .05) related to the probability of survival one year after a dormant season fire, regardless of species, based on logistic regression analyses. The full model used to predict survival after one burn, which included initial basal diameter and height, and their interaction, had strong support for being one of the best models considered for flowering dogwood (w_i = 0.94) and for black oak (w_i = 0.88). The full model had moderate support (w_i = 0.62) in explaining blackgum's response to a prescribed burn. For the other species, subset models that contained intial basal diameter, intial height, or a combination of the two variables had moderate support for being in the set of best survival models (w_i varying from 0.25 to 0.63). For all species, there was no support (w_i = 0) for the null hypothesis model (intercept only model). The Hosmer Lemeshow goodness-of-fit test on the full model showed a good fit of the model for all species except black oak. In

Table 4—Fire damage to advance reproduction one growing season after one or more (i.e., 3 to 4) springtime prescribed burns

Species	Sample size (1/3+) burns	Mortality 1 burn	Mortality 3+ burns	Topkill with sprouts 1 burn	Topkill with sprouts 3+ burns	Total damage 1 burn	Total damage 3+ burns	Minimum basal diameter for < 10 percent mortality 1 burn	Minimum basal diameter for < 10 percent mortality 3+ burns
		percent						inches	
White oak	346/255	5	22	52	63	57	85	0.2	4.5
Post oak	180/145	9	21	64	74	73	95	0.3	2.0 (3 burns) 2.6 (4 burns)
Chinkapin oak	106/54	5	17	76	74	81	91	0.2	0.1 (3 burns) 2.2 (4 burns)
Scarlet oak	156/121	10	44	65	53	75	97	0.3	5.1
Black oak	224/170	10	28	70	69	80	97	0.7	1.6 (1 foot) 1.8 (5 foot) 2.2 (10 foot)
Blackjack oak	56/37	4	41	80	59	84	100	0.2	> 6
Hickory	723/520	3	17	94	70	97	87	0.1	6 (< 10 foot) 1.5 (10 foot)
Flowering dogwood	316/245	5	52	82	38	87	90	1.75	> 6
Blackgum	239/185	2	50	49	38	51	88	0.1	> 6 (1-10 foot)
Sassafras	286/216	0	9	79	84	79	93	0.1	0.1
White ash	65/44	14	25	61	70	75	95	0.5	0.6 (1-5 foot)
Shortleaf pine	74/18	38	39	18	39	56	78	3.75	> 6

other studies, tree stem diameter has been correlated to survival after burning because it is directly related to bark thickness and tree height, and hence to a tree's ability to resist heat injury to the cambium or to the crown (Hare 1965, Loomis 1973, Hengst and Dawson 1994, Regelbrugge and Smith 1994).

The probability of survival increased rapidly with increasing basal diameter for most species, but less so with flowering dogwood and shortleaf pine (fig. 2). In general, the minimum basal diameter needed for survival to be at least 90 percent was less than 0.5 inch for most species (table 4). However, flowering dogwood and shortleaf pine advance reproduction had to be larger than 1.8 and 3.8 inches, respectively, before their chances of survival exceeded 90 percent.

Total fire damage (sum of mortality and topkill) was high after one dormant season fire (table 4). Most of the fire damage to advance reproduction was topkilled seedlings that sprouted during the following growing season. Waldrop and Lloyd (1991) observed that low to moderate intensity surface fires can topkill most hardwood stems that are less than 4 inches in diameter, and that mortality declines as

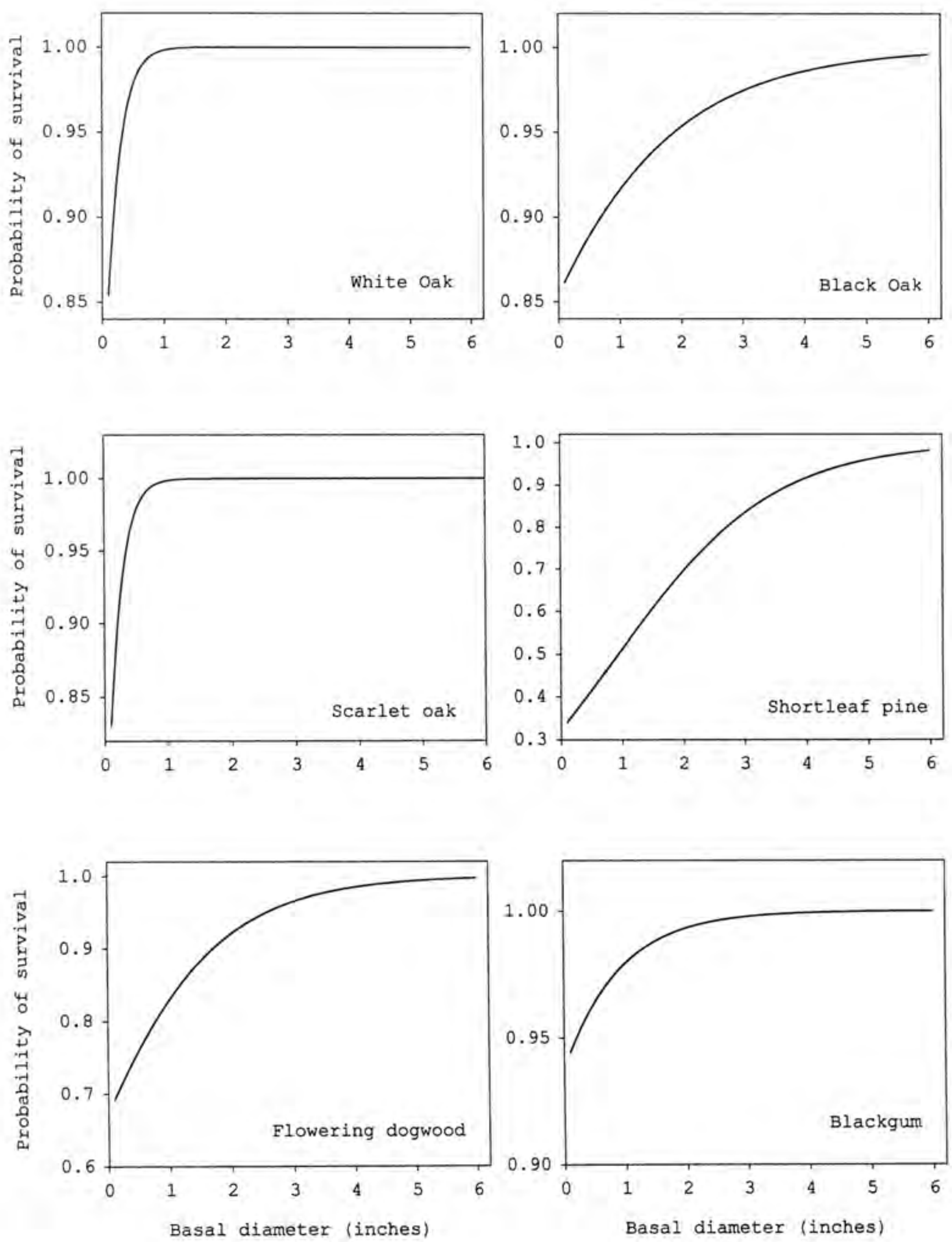

Figure 2—The probability that advance reproduction will be alive one growing season after a dormant season prescribed fire based on the initial basal diameter and species. All logistic models shown were significant (α = 0.05) and had at least moderate support according to the Akaike weight (w_i).

tree diameter increases above 4 inches. Dormant season fires also promote hardwood sprouting after topkill because carbohydrate reserves in the root system are still at relatively high levels. White oak, blackgum, and shortleaf pine had the lowest overall amount of fire damage.

2001 Fire Damage – After One, Three, or Four Burns

After three or four burns, total fire damage (mortality and topkill) was high for all species and was often greater than it was after one burn (table 4). For advance reproduction that was burned three or four times, a higher proportion of the damage was due to mortality and less of the damage was topkill compared to trees that had been burned only once. Mortality after three or more burns increased notably in scarlet oak, blackjack oak, flowering dogwood, and blackgum. Moderate increases in mortality were seen in the other species. Sassafras showed the greatest tolerance to being burned repeatedly. For most species, basal diameters associated with 90 percent or greater survival were substantially higher after three or more burns than they were after one burn (table 4). For some species, the threshold diameter varied with tree height or with the number of burns experienced by the advance reproduction. Sassafras showed a tremendous ability to tolerate being burned repeatedly with more than 90 percent of the stems surviving even for small diameter trees (e.g., 0.1 inches).

For most species, initial basal diameter, initial height, and number of burns were significantly ($p < 0.05$) related to the probability of survival one growing season after either one, three or four dormant season burns. The full logistic model, which included initial basal diameter and height, their interaction and the number of burns, had strong support for being the best model ($w_i = 0.99$) for blackgum and hickory, and moderate support (w_i ranging from 0.32 to 0.65) for black oak, flowering dogwood, and white oak. The initial basal diameter and number of burns model had moderate support (w_i varying from 0.22 to 0.47) for white ash (*Fraxinus americana* L.), post oak, chinkapin oak, scarlet oak, and white oak. For blackjack oak, the initial basal diameter model ($w_i = 0.54$) and the number of burns model ($w_i = 0.36$) had the most support in predicting survival of advance reproduction. The survival of blackjack oak advance reproduction was as low as 62 percent after four consecutive burns and as high as 87 percent after one burn. The number of burns model also had moderate support ($w_i = 0.42$) for predicting survival in chinkapin oak, where survival ranged from 98 percent for trees subjected to only one burn to 84 percent for trees burned as many as four consecutive years. Survival of sassafras advance reproduction was high enough, even after four consecutive burns (i.e., 91 percent), that all models tested were statistically insignificant ($p > 0.05$). For all species, there was no support ($w_i = 0$) for the null hypothesis model (intercept only model). The Hosmer Lemeshow goodness-of-fit test on the full model showed a good fit of the model for all species except scarlet oak and hickory.

The probability of survival increased with increasing initial basal diameter for all oak species (fig. 3) and white ash. In contrast, survival probabilities declined with increasing stem diameter in hickory, blackgum and flowering dogwood species regardless of tree height or number of burns. In these species, tall trees had higher chances of surviving than did short trees of the same basal diameter, regardless of the number of fires. In flowering dogwood, the effect of height on survival was most pronounced in smaller diameter trees, whereas the opposite was observed in blackgum and black oak advance reproduction.

Survival for all species was greatly reduced after three or four fires (fig. 3). In many cases, survival of advance reproduction was 20 to 30 percent less after four fires than after one. Differences in survival between trees subjected to one or four burns were greatest for small diameter trees, but survival probabilities converged at larger basal diameters (e.g., 3-inch and larger trees). In general, multiple burns lowered survival in flowering dogwood and blackgum more than in most of the oaks, with the exception of scarlet oak and blackjack oak. Survival in scarlet oak was reduced by nearly 40 percent for small diameter advance reproduction, but it improved with increasing basal diameter, though not to the extent that was seen in other oak species.

Recovery of Height and Understory Woody Structure

The effect of fire and time since the last fire on the height of sprouts from advance reproduction that were topkilled was similar among the species. We compared pre- and post-burn height distributions in the single burn and four burn treatments for oak species combined and for flowering dogwood, a major competitor of oak reproduction (Dey and others 1996). Post-burn height distribution of oaks was substantially different than the initial distribution four growing seasons after a burn (fig. 4). One burn caused densities of sprouts in the smallest height classes (< 4 feet tall) to increase above initial levels, and eliminated many of the taller advance reproduction. The tallest oak sprouts had only made it into the 10-foot height class in four years since the burn, approximately 14 feet or more shorter than the tallest pre-burn stems. This slow recovery in height after each fire may be due to sprouts growing under a forest canopy that averaged 79 ft^2 per acre (range 38 to 160) and 69 percent stocking (range 36 to 120). Dey and Jensen (2002) found that overstory densities that averaged 62 ft^2 per acre inhibited the height growth of oak stump sprouts. Further, we found that the tallest oak sprouts were less than 4 feet one season after four consecutive burns, and most of the advance reproduction were less than 2 feet tall. Similar results were seen in flowering dogwood. Waldrop and Lloyd (1991) also found that fire increased the density of trees in the smaller size classes by causing shoot dieback and formation of sprout clumps, and by promoting the establishment of new seedlings in South Carolinian Coastal Plain forests, where relatively young stands had been subjected to a range of periodic fire treatments over 40 years.

SUMMARY

One dormant season prescribed burn reduced the size distribution of advance reproduction for common hardwood species found in the Missouri Ozark Highlands. Most stems of advance reproduction less than six inches in basal diameter were damaged by fire, usually by shoot dieback followed by formation of sprout clumps. Mortality of advance reproduction was generally low in all species after one burn. We found that the probability of survival was significantly

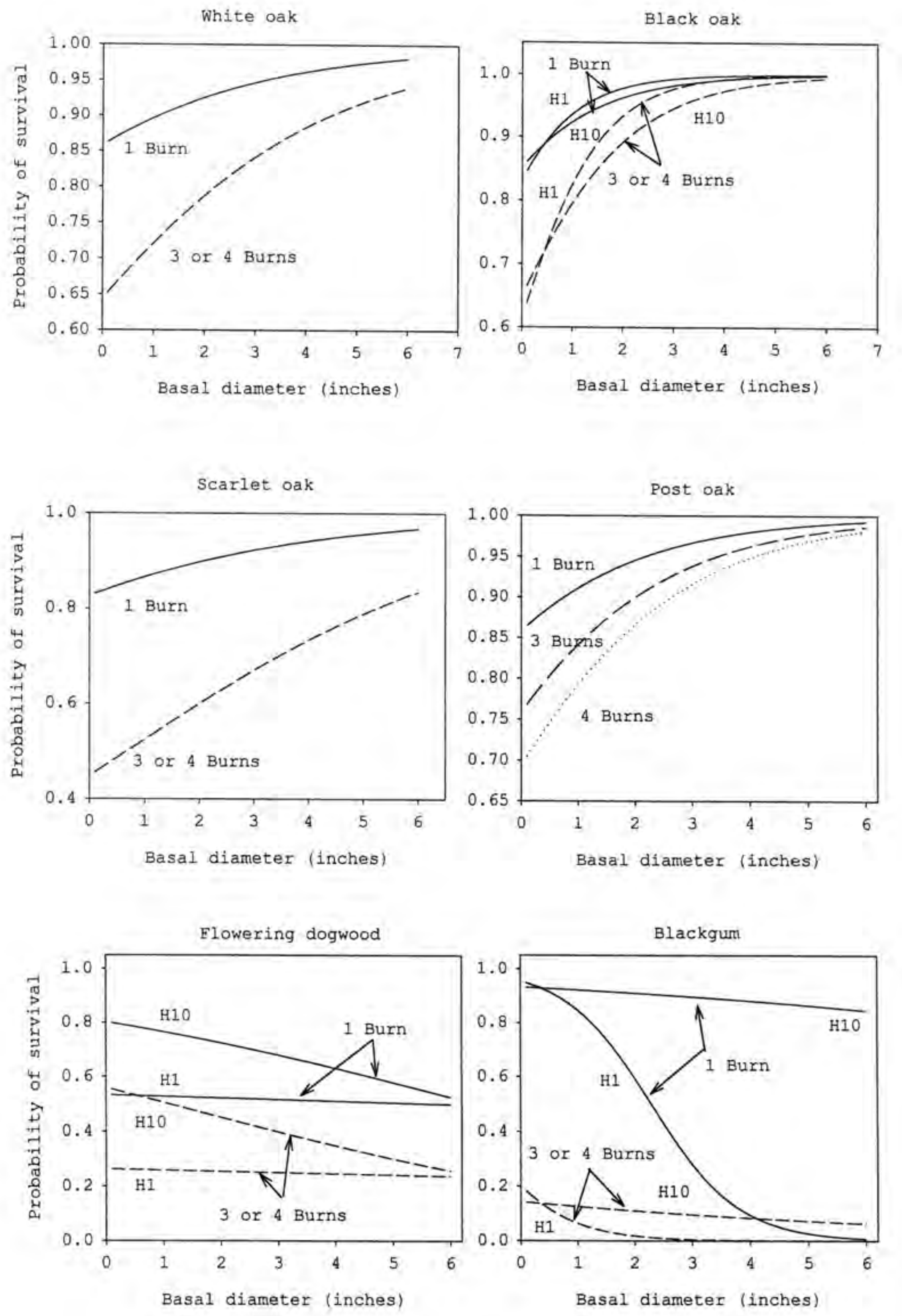

Figure 3—The probability that advance reproduction will be alive one growing season after four consecutive dormant season burns, two years after three burns, or four years after a dormant season prescribed fire based on the initial basal diameter, initial height and species. All logistic models shown were significant (α = 0.05) and had at least moderate support according to the Akaike weight (w_i).

related to size of advance reproduction and that there were real differences among the species studied. Recovery of height by the hardwood sprouts is slow under a mature forest canopy. Thus, one fire can significantly modify the structure of the woody understory in upland oak forests for up to four years, but it does little to alter the composition of the advance reproduction. By virtue of reducing the diameter and height of advance reproduction, a single prescribed burn predisposes sprouts to experience more severe damage and higher rates of mortality from subsequent fires.

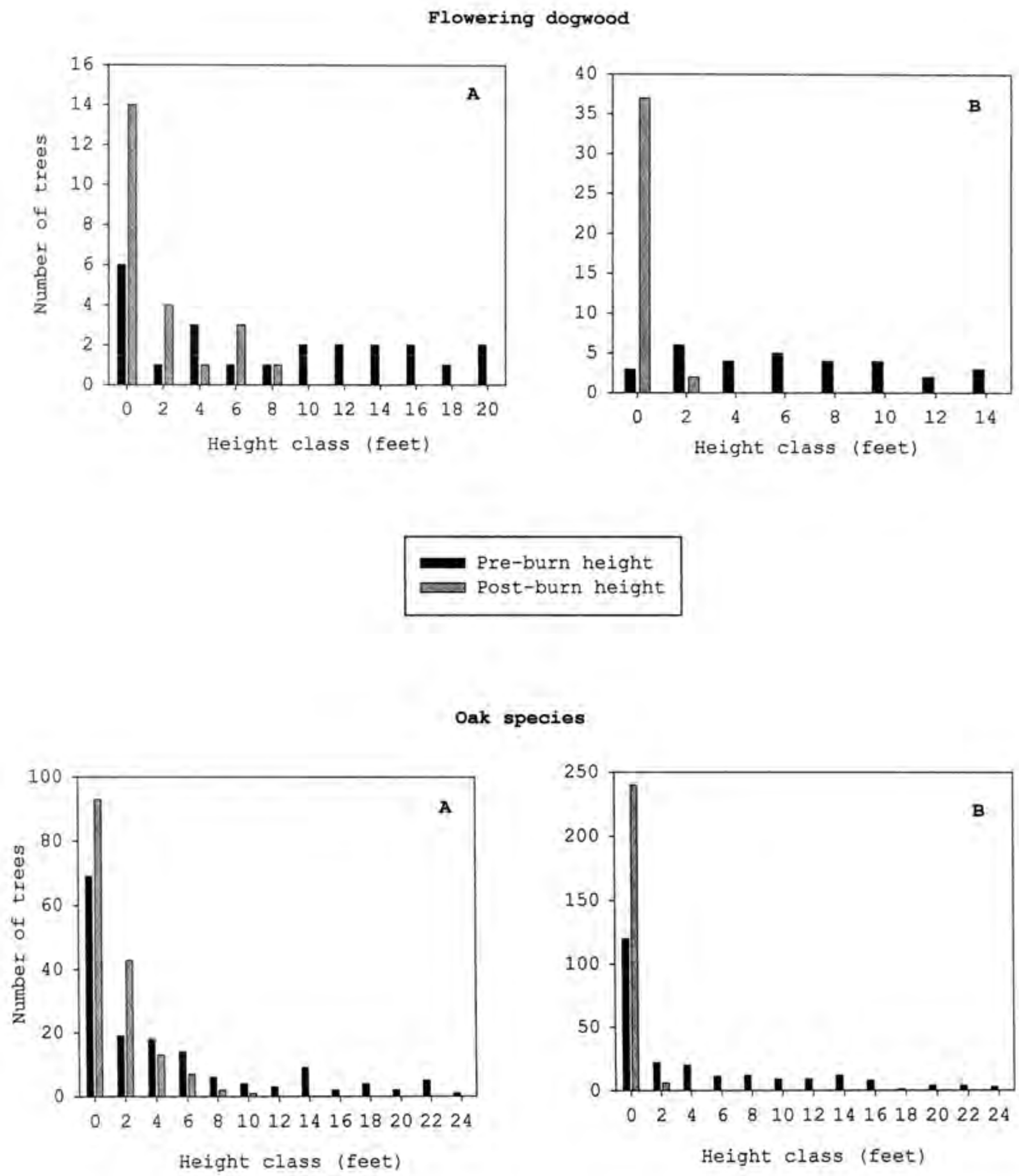

Figure 4—Pre-and post-burn height distributions of flowering dogwood and oak advance reproduction that sprouted after being topkilled by one, or four consecutive dormant season fires. Post-burn heights are shown (A) four years after one burn and (B) one year after four burns.

Three or four consecutive dormant season burns caused substantially higher mortality to advance reproduction and consequently greater levels of total fire damage. Mortality of flowering dogwood and blackgum advance reproduction increased substantially under a regime of frequent to annual fire. Mortality of oak and hickory advance reproduction was also increased to a lesser degree by frequent burning. Among the oaks, scarlet and blackjack advance reproduction were most vulnerable to repeated burning, whereas black, post, and white oak were intermediate. Overall, repeated burning in the dormant season favors oak and hickory reproduction.

ACKNOWLEDGMENTS

We thank The Nature Conservancy for their cooperation in this study, for their help in data collection, and for access to their property. They also funded and implemented the prescribed burning treatments. The Missouri Department of Conservation provided funding for field crews to collect data.

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